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<p>(21) International Application Number: PCT/US97/17776</p> <p>(22) International Filing Date: 2 October 1997 (02.10.97)</p> <p>(30) Priority Data: 60/027,354 2 October 1996 (02.10.96) US 08/911,792 15 August 1997 (15.08.97) US</p> <p>(71) Applicant: E.I. DU PONT DE NEMOURS AND COMPANY [US/US]; 1007 Market Street, Wilmington, DE 19898 (US).</p> <p>(72) Inventors: SAUM, Kenneth, Ashley; 203 Wilson Road, Newark, DE 19711 (US). SANFORD, William, Michael; 52 Fawn Lane, Kennett Square, PA 19348 (US). DIMAIO, William, Gerald, Jr.; 1306 Longmeadow Road, Boothwyn, PA 19061 (US). HOWARD, Edward, George, Jr.; 844 Old Public Road, Hockessin, DE 19707 (US).</p> <p>(74) Agent: EVANS, Craig, H.; E.I. du Pont de Nemours and Company, Legal Patent Records Center, 1007 Market Street, Wilmington, DE 19898 (US).</p>		<p>(81) Designated States: AL, AM, AU, AZ, BA, BB, BG, BR, BY, CA, CN, CU, CZ, EE, GE, HU, ID, IL, IS, JP, KG, KP, KR, KZ, LC, LK, LR, LT, LV, MD, MG, MK, MN, MX, NO, NZ, PL, RO, RU, SG, SI, SK, SL, TJ, TM, TR, TT, UA, UZ, VN, YU, ARIPO patent (GH, KE, LS, MW, SD, SZ, UG, ZW), Eurasian patent (AM, AZ, BY, KG, KZ, MD, RU, TJ, TM), European patent (AT, BE, CH, DE, DK, ES, FI, FR, GB, GR, IE, IT, LU, MC, NL, PT, SE), OAPI patent (BF, BJ, CF, CG, CI, CM, GA, GN, ML, MR, NE, SN, TD, TG).</p> <p>Published <i>With international search report. Before the expiration of the time limit for amending the claims and to be republished in the event of the receipt of amendments.</i></p>
<p>(54) Title: PROCESS FOR MEDICAL IMPLANT OF CROSS-LINKED ULTRAHIGH MOLECULAR WEIGHT POLYETHYLENE HAVING IMPROVED BALANCE OF WEAR PROPERTIES AND OXIDATION RESISTANCE</p> <p>(57) Abstract</p> <p>A medical implant of ultrahigh molecular weight polyethylene having an improved balance of wear properties and oxidation resistance is prepared by irradiating a preform of ultrahigh molecular weight polyethylene, annealing the irradiated preform in the absence of oxygen to a temperature at or above the onset of melting temperature, and forming an implant from the stabilized cross-linked polymer. Implants prepared according to the process of the present invention have comparable oxidation resistance and superior wear performance compared to unirradiated ultrahigh molecular weight polyethylene.</p>		

TITLE

Process for Medical Implant of Cross-linked Ultrahigh Molecular Weight
Polyethylene Having Improved Balance of
Wear Properties and Oxidation Resistance

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BACKGROUND OF INVENTIONField of Invention

This invention relates to a process for forming medical implants of cross-linked ultrahigh molecular weight polyethylene having an improved balance of wear properties and oxidation resistance.

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Description of Related Art

It is known in the art that ultrahigh molecular weight polyethylene (UHMWPE) can be cross-linked by irradiation with high energy radiation, for example gamma radiation, in an inert atmosphere or vacuum. Exposure of UHMWPE to gamma irradiation induces a number of free-radical reactions in the polymer. One of these is cross-linking. This cross-linking creates a 3-dimensional network in the polymer which renders it more resistant to adhesive wear in multiple directions. The free radicals formed upon irradiation of UHMWPE can also participate in oxidation which reduces the molecular weight of the polymer via chain scission, leading to degradation of physical properties, embrittlement and a significant increase in wear rate. The free radicals are very long-lived (greater than eight years), so that oxidation continues over a very long period of time resulting in as much as a 5-fold increase in the wear rate as a result of oxidation over a period of about 5 years. As such, the wear rate of traditionally irradiated materials is significantly greater than unirradiated materials.

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Sun et al. U.S. Patent 5,414,049, which patent is hereby incorporated by reference, discloses a process for improving the oxidation resistance of medical implants which have been sterilized with radiation. In a preferred embodiment, a raw polymeric material is obtained by forming a virgin resin powder from which air and moisture have been removed prior to the forming process. The forming process, e.g. ram extrusion or compression molding of the powder is also preferably carried out in an inert low oxygen atmosphere. A medical implant is formed from the raw material, e.g. an olefinic material such as UHMWPE, and is

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allows one to use lower levels of irradiation for cross-linking than would be effective for sterilization of UHMWPE. Additionally, the heat treatment step following irradiation may be performed at temperatures near or above the melting point, which would distort the shape of a machined or molded implant which has been packaged for final sterilization. Heat treatment near or above the melting point results in improved molecular mobility, elimination of free radicals in the crystalline regions of the polymer which cannot occur at temperatures below the melt, and increased cross-linking and reduced oxidation in aged samples. When heat treatment is carried out at lower temperatures, incomplete quenching of free radicals results in residual oxidation upon aging. By separating the irradiating and annealing steps, the process of the current invention also avoids the need to irradiate in the melt, which is difficult to achieve on a commercial scale. An additional object of the current invention is to prepare a medical implant of cross-linked UHMWPE having improved wear properties without the use of chemical cross-linking agents. Medical implants formed from the cross-linked UHMWPE material of the current invention may be packaged in an air-permeable package and sterilized using non-irradiative methods such as gas plasma or ethylene oxide, eliminating the need to package the implants in an inert atmosphere. The cross-linked UHMWPE of the current invention can also be used in nonmedical applications requiring high wear resistance.

SUMMARY OF THE INVENTION

The current invention pertains to a process for preparing cross-linked ultrahigh molecular weight polyethylene useful in medical implants. The process involves irradiating a preform of ultrahigh molecular weight polyethylene, preferably with gamma radiation. Optionally, the preform may be annealed prior to irradiation in an inert atmosphere without the application of external pressure. The irradiated preform is then annealed in a substantially oxygen free atmosphere at a temperature at or above the onset of melting temperature, preferably near or above the peak DSC melting point, for a sufficient time to substantially recombine (eliminate) all the free radicals and crosslink the ultrahigh molecular weight polyethylene. This annealing step may be done under isostatic or hydrostatic pressure. The annealed preform is cooled while maintaining the oxygen free

by reference. The UHMWPE preform material does not contain stabilizers, antioxidants, or other chemical additives which may have potential adverse effects in medical applications.

The process of the current invention includes the steps of irradiating a UHMWPE preform to form free radicals and cross-link the UHMWPE, annealing the irradiated UHMWPE preform at elevated temperature in a substantially oxygen free atmosphere to eliminate any free radicals remaining from the irradiation step, thus further cross-linking and increasing the oxidation resistance of the irradiated UHMWPE, and forming a medical implant from the annealed cross-linked preform. Gamma radiation is preferably used in the irradiation step, however electron beam or x-ray radiation may also be used. Ultrahigh molecular weight polyethylene prepared according to the process of the current invention has an improved balance of wear properties and oxidation resistance. The increased cross-linking results in reduced swell ratios, generally less than about 5, and improved wear performance with comparable oxidation resistance relative to unirradiated UHMWPE.

The preform is preferably irradiated in the solid state with gamma radiation at a dose of about 0.5-10 Mrad using methods known in the art. Preferably, the preform is irradiated at a dose of about 1.5 - 6 Mrad. Radiation doses of less than about 0.5 Mrad generally provide insufficient cross-linking to provide the desired increase in wear properties in the final implant. While doses of greater than 10 Mrad may be used, generally the additional improvement in wear properties that is achieved by the higher dose is offset by increasing brittleness of the UHMWPE due to higher levels of cross-linking. Ultrahigh molecular weight polyethylene prepared using the process of the current invention generally has a percent elongation at break of at least about 250, single notch Izod strength of at least about 15 ft lb/in of notch, preferably at least about 17 ft lb/in of notch, and double notch Izod strength of at least about 35 ft lb/sq in. UHMWPE which has been pre-annealed or annealed at temperatures greater than about 280°C generally have a percent elongation at break of at least about 400, preferably at least about 500. The irradiation step is generally performed at room temperature, however higher temperatures may be used.

preferably at a temperature near or above the peak melting temperature of the irradiated heat-treated polymer for a time of 2-120 hours, preferably 5-60 hours, more preferably 12-60 hours. The onset of melting temperature is defined herein as the temperature at the intersection of the baseline and steepest negative slope of the DSC melting endotherm. The baseline intersects the initial portion of the melting endotherm and is tangent to the final portion of the curve. The peak melting temperature is defined herein as the location of the peak of the melting endotherm. The onset of melting temperature for irradiated, heat-treated UHMWPE is generally about 120°C and the peak melting temperature is generally between 135°C and 140°C. An especially preferred embodiment of the current invention is irradiation with a dose of 1.5 - 6 Mrads followed by heat treatment at 150-170°C for a period of 6-60 hours, more preferably 12-60 hours.

The temperature and hold time that is sufficient to react substantially all of the free-radicals may be determined by measuring the oxidation of the samples using the method described below. Preferably, the temperature and hold time are chosen such that oxidation levels of less than about 0.2 carbonyl area/mil sample thickness, preferably less than about 0.1 carbonyl area/mil sample thickness, after aging as measured by this method are obtained. Heat treatment at or above the onset of melting temperature results in improved molecular mobility and elimination of free radicals in the crystalline regions of the polymer and increased cross-linking and reduced oxidation in aged samples. When heat treatment is carried out at lower temperatures, elimination of free radicals is less complete resulting in higher levels of residual oxidation upon aging.

Standard UHMWPE may be irradiated and pressure recrystallized to convert the UHMWPE into an extended chain conformation by conducting the heat treatment step using the temperatures and pressures disclosed for pressure recrystallization in U.S. 5,478,906. In pressure recrystallizing UHMWPE, the polymer is placed in a pressure vessel in water and enough pressure to withstand the pressure the water will develop at the operating temperatures. The temperature of the vessel is raised to melt the polyethylene which generally melts at 135-150°C at one atmosphere, and about 200°C at 50,000 psi. The time required to melt the polymer depends on the size of the UHMWPE preform used.

using non-radical-forming methods. Because the implant is oxidatively stabilized, it is not necessary to package the finished implant in an inert atmosphere. For example, the implant can be packaged in air-permeable packaging and sterilized using gas plasma or ethylene oxide methods which are known in the art. For example a PLAZLYTE® gas plasma sterilization unit, manufactured by Abtox (Mundelein, Illinois), may be used.

In an alternate embodiment of the current invention, the UHMWPE preform is pre-annealed prior to the irradiation step. In the pre-annealing step, the preform is subjected to a temperature of 280°C - 355°C, preferably 320°C - 355°C, for at least 0.5 hour, preferably at least 3 hours, in an inert atmosphere, without the application of external pressure. It is generally desirable to heat the polymer as close as possible to, without reaching, its decomposition temperature. The pre-annealed preform is then cooled non-precipitously to a temperature of about 130°C or below, the rate of cooling being such that temperature gradients producing internal stresses in the article are substantially avoided. Rapid cooling, such as by immersion in cold water, should be avoided as it causes internal voids to form. It is generally convenient to allow the polymer to cool wrapped in insulation. The pre-annealed preform has improved elongation, impact resistance, and crystallinity over the starting UHMWPE. The cooled pre-annealed preform is then irradiated and annealed as described above.

TEST METHODS

Unless noted otherwise, test specimens were prepared from the interior of the preform rods.

Type IV tensile specimens conforming to ASTM D-638 were machined from the UHMWPE sample materials. The test specimens were mounted in a Lloyd LR10K mechanical test frame and tested for the tensile yield stress (TYS), ultimate tensile stress (UTS) and percent elongation according to ASTM D-638. Type IV specimens were used to measure UTS, TYS, and percent elongation for Examples 1-27, and Comparative Examples A-C.

Type I tensile specimens were machined from the UHMWPE samples and mounted in the test frame. Tensile modulus was measured on these samples according to ASTM D-638. Type I tensile specimens were also used to measure

22.5 degrees. Impact strength was also measured using double notched Izod specimens and the test method described in ASTM F-648 Annex A1.

Oxidative aging was performed on specimens which were wrapped in porous breather fabric to prevent close packing of the specimens and allow free gas access to all surfaces. The specimens were then loaded into a 4 in. x 8 in. cylindrical pressure bomb and sealed. The bomb was pressurized to 5 atmospheres (73.5 psi) with oxygen and heated with cylindrical band heaters to 70°C and held for 14 days. Aged wear test results were obtained by aging the hip cups using this procedure prior to wear testing. Similarly, aged Izod specimens for double notch impact strength measurements were prepared according to ASTM F-648 Annex A1 followed by oxidative aging prior to strength measurements.

Specimens for oxidation measurements were cut from the interior of the cooled preform rods after gamma-irradiation and annealing. The samples were 45 degree wedge cuts from 0.5 inch thick by 2.5 inch diameter disks. Oxidation measurements were made on 250 micron thick sections prepared by cutting the wedge-shaped specimens through their thickness using a band saw. A 250 micron thick slice was microtomed off the freshly exposed surface and analyzed using FTIR. Aged oxidation results were obtained from wedge cuts that were aged according to the oxidative aging procedure described above prior to preparing the 250 micron thick section. The sample was mounted in a Digilab FTIR fitted with a microscope with a motorized stage. The FTIR aperture was focused through the microscope to allow measurement of the infrared absorbance in a small (25 micron x 200 micron) section of the sample. The microscope stage was moved by a stepper motor in increments of 50 microns to measure the carbonyl absorbance at a number of locations from the surface down to a depth of 4 mm. Oxidation was quantified based on the absorbance of the carbonyl peaks at 1670 - 1730 wavenumbers as compared to a reference peak corresponding to methylene stretching along the polymer backbone at 4250 wavenumber using the method of Nagy & Li. A Fourier Transform Infrared Technique For The Evaluation of Polyethylene Bearing Materials. Transactions. 16th Annual Meeting. The Society for Biomaterials. 3:109. 1990. An average oxidation level was calculated by

approximately 6 million, a peak melting point of about 135°C, and a percentage crystallinity of about 45-55%.

Examples 1-3

5 Rods of UHMWPE as described above were placed in separate pouches of heat sealable packaging foil having a MYLAR® polyester coating, SP Class E style 1.40 sleevestock (Shield Pack, Inc., West Monroe, La), flushed with nitrogen and then evacuated. This procedure was repeated and the pouches were then sealed under vacuum. The rod of Example 1 was irradiated with a dose of 1 Mrad
10 of gamma irradiation from a Cobalt-60 source. Gamma irradiation was performed by Isomedix (Morton Grove, Illinois). The rods of Examples 2 and 3 were irradiated with doses of 2.5 Mrads and 5 Mrads, respectively. After irradiation, the packaged rods were placed individually in an oven at a temperature of 325°C and held at that temperature for 4.5 hours. At the end of 4.5 hours, the rods were
15 cooled in the oven at about 20°C/hr to ambient temperature in their packages. The cooled rods were then removed from their packages and mechanical and physical properties and oxidation were measured as described above. The results and process conditions are shown in Table I. These examples show excellent oxidation resistance under both aged and unaged conditions compared to
20 Comparative Examples A, B, and C. The effect is greatest for Example 3 (vs. Comparative Example C) which was irradiated at the higher dose of 5 Mrads. Aged and unaged oxidation resistance for Examples 1-3 is comparable to unirradiated Example D. This improved performance is due to the substantially complete quenching of the free radicals by annealing at 325°C. These examples
25 also shown an unexpected benefit of a large increase, approximately 2x, in the % elongation to break, attributed to the temperature of the annealing. Elongation generally increases significantly for samples which are annealed or pre-annealed at temperatures of greater than about 280°C.

30 Comparative Examples A-C

UHMWPE rods for comparative Examples A and C were packaged under vacuum as described in Examples 1-3, and irradiated at doses of 1 Mrad and 5.0

recrystallization was conducted by scaling the vessel and pressurizing with water to about 5000 psi. The vessel was then heated over a period of 1.5 hours to 250°C. After 2 hours, the pressure was raised to 50,000 psi and maintained there for the rest of the pressure treatment. After 1 to 2 hours at 250°C, the vessel was
5 allowed to cool to 75°C at which point the pressure was released and the product recovered. Additional rods were also pressure recrystallized using the above procedure at 39,000 and 34,000 psi. The results are shown in Table II.

Examples 16-21

10 In these examples, the 3 in. diameter GUR 415 UHMWPE rods were pre-annealed at 325°C for 4.5 hours in nitrogen, cooled in nitrogen at approximately 20°C/hr. and then sealed in aluminum foil/polyethylene bags under nitrogen. The bars were then irradiated with gamma rays. After aging one month, the polymers were pressure recrystallized as described above. Process conditions and results
15 are given in Table III. The polymer was converted to extended chain form only at higher pressure. The samples treated with 50,000 psi during pressure recrystallization had higher melting points, higher heats of fusion, higher tensile moduli, higher maximum strengths, higher tensile strength at yield, higher Izod impact strength, and improved creep resistance.

20 The pre-annealed samples of Examples 16-21 have higher elongations than the corresponding samples of Examples 4, 5, 7, 8, 10 and 11 which were not pre-annealed.

Examples 22-23

25 In these examples, 3 in. diameter GUR 415 UHMWPE rods were gamma irradiated at 2.5 Mrad and 5.0 Mrad in nitrogen and pressure recrystallized at 39,500 psi using the process described in Examples 4-15. Irradiation conditions and results are given in Table IV.

30 Examples 24-25

In these examples, 3 in. diameter GUR 415 UHMWPE rods were gamma irradiated at 2.5 Mrad and 5 Mrad, and then subjected to pressure recrystallization

Examples 31-33

UHMWPE rods 31, 32 and 33 were packaged and processed as described in Example 3 (5 Mrad) except that the rods were heated to 155°C for 6, 24 and 48 hours respectively, removed from the oven, and cooled. The process conditions, mechanical and physical properties are shown in Table V. These examples show that UHMWPE exposed to 5 Mrads of gamma irradiation then annealed at 155°C also gives excellent oxidation resistance. It also shows that the radiation dose reduces the impact strength and the elongation. A comparison of these swell ratios, 2.6, with Examples 28-30 and D, show that crosslinking is increased with radiation dose. An unaged wear rate of 0.8 mg/million cycle and an aged wear rate of 0.6 mg/million cycles were measured for Example 32 after 2.5 million cycles. The wear rate of Example 32 is greatly reduced compared to Examples 30, B and D. By performing both the irradiation and annealing steps, the wear and oxidation resistance of this material is greatly improved over material that is irradiated but not annealed. Oxidation resistance is comparable to unirradiated polymer (Comparative Example D) and wear performance is significantly improved.

Example 34-36

UHMWPE rods 34, 35 and 36 were packaged and processed as described in Example 3 (5 Mrad) except that the rods were heated to 200°C for 6, 24 and 48 hours respectively, removed from the oven and cooled. The process conditions, mechanical and physical properties are shown in Table V. These examples show that annealing at 200°C is also effective for producing an oxidation resistant material.

Example 37

This rod was packaged and processed as described in Example 3 (5 Mrad) except the rod was heated to 120°C for 48 hours, removed from the oven, and cooled. An unaged wear rate of 5 mg/million cycles was measured after 5 million cycles. Results are shown in Table V. This example shows the improved wear resistance of a material crosslinked at 5 Mrads and annealed at 120°C for 48 hours

TABLE I

Example	1	2	3	A	B	C	D
5 Gamma dose (Mrad)	1	2.5	5	1	2.5	5	0
Hold Temp/Time (deg C/hr)	325/4.5	325/4.5	325/4.5	none	none	none	none
<u>Mechanical Properties</u>							
<u>Type I Samples</u>							
10 Modulus (kpsi)	147.8	148.5	144.3		143.1		137.0
Secant Modulus (kpsi)				122.3			
<u>Type IV Samples</u>							
15 TYS	3.544	3.454	3.429	3.553	3.507	3.669	3.396 (Type I)
UTS	5.603	5.481	5.644	5.324	5.47	5.511	5.152 (Type I)
% Elongation	805	700	613	310	340	267	343 (Type I)
Impact Strength - Double Notched Izod (ft-lb/sq in)							
(unaged)					48.1		48.1
(aged)					4.8		
20	<u>Physical Properties</u>						
Density (g/cc)	0.9461	0.9442	0.9409	0.9356	0.9378	0.9379	.9344
Hf (J/g)	170.9	184.2	161.6	145	163.3	165.8	
% Crystallinity	58	63	55	50	56	57	51
25 Peak Tm (°C)	138.1	137.1	135.6	139.4	138.7	137.4	136.7
Onset of melting T (°C)	126.0	125.8	123.0		127.2		130.8
Oxidation(unaged)	0.067	0.048	0.068	0.154	0.172	0.398	.054
oxidation(aged)	0.14	0.078	0.117	0.527	1.107	2.78	.075
Swell Ratio							24.1
30 Wear Rate (mg/million cycles)							
(unaged)					15		30
(aged)					88		33

TABLE III

**Physical Properties of Pre-Annealed (325°C) UHMWPE,
Gamma Irradiated and Pressure Recrystallized**

5	Example	16	17	18	19	20	21
	Dose (Mrad)	0.5	0.5	1	1	2	2
10	Pressure (kpsi)	50	39	50	39	50	39
	Tensile Strength, psi						
	Yield	4277	3773	4066	3543	4051	3594
15	Max	5289	4696	5145	4332	5142	4119
	Break	4532	4695	4582	4331	4604	4117
	Modulus (kpsi)	335.2	276.0	296.9	219.0	293.6	266.5
20	Elongation. %						
	Yield	5	7.5	5	7.5		7.5
	Break	>432	>500	>450	417	>400	388
	IZOD	24.0	20.5	24.2	21.6	23.6	21.9
25	(ft lb/in of notch)						
	Deformation.(%)	0.7	2.8	0.8	1.8	1.2	2.3
	24 hrs, 23 deg C, 1000 psi						
30	DSC						
	mp, deg C	148.8	140.7	148.9	140.8	148.6	140.8
	Hf(J/g)	217	175	207	185.9	202.8	177.9

TABLE V

Example	28	29	30	31	32	33	34	35	36	37
Gamma dose (Mrad)	2.5	2.5	2.5	5	5	5	5	5	5	5
Heat/hold time (°C/hrs)	155/6	155/24	155/48	155/6	155/24	155/48	200/6	200/24	200/48	120/48
MECHANICAL PROPERTIES										
Type I Tensile Samples										
Modulus (kpsi)	115.7	114.3	124.9	111.9	116.2	110.8	112.4	118.4	108.7	
Secant mod. (kpsi)	106.5	104.6	114.3	99.3	104.9	101.8	100.6	109.6	98.5	
TYS (kpsi)	3.080	3.100	3.056	3.068	3.147	3.113	3.075	3.115	3.094	
UTS (kpsi)	5.130	5.436	5.024	5.037	5.238	5.267	4.698	5.053	5.000	
% Elongation	331	326	321	272	273	283	265	263	278	
Impact Strength, Double Notch (ft lb/in ²)										
(unaged)	44.0	44.7	44.0	36.2	35.1	37.3	37.3	38.3	36.9	
(aged)	44.0	44.6	42.7	36.0	35.7	37.8	37.0	36.8	37.1	
Deformation (%) (24 hrs, 23 °C, 1 kpsi)	1.5	1.1	1.4	1.2	1.6	1.0	1.0	1.2	1.2	
PHYSICAL PROPERTIES										
Density (g/cc)	0.9292	.9289	.9298	.9295	.9299	.9292	.9292	.9295	.9285	
Hf (J/g)	135.6	146.3	132.5	141.2	128.5	147.4	131.4	142.9	145.8	
% Crystallinity	47	50	45	49	44	51	45	49	50	
Peak Tm (°C)	134.7	134.4	135.1	137.8	136.6	134.9	134.8	137.3	135.8	
Onset of melting										
T _i (°C)	121.8	123.6	122.7	121.3	120.9	120.1	119.9	121.8	120.5	
oxidation										
(unaged)	.067	.052	0.064	0.052	0.053	0.065	0.065	0.055	0.110	
(aged)	.059	.057	0.076	0.069	0.064	0.081	0.074	0.140	0.082	
Swell ratio	3.9	3.3	3.7	2.5	2.6	2.6	2.8	2.4	2.7	
Wear rate(mg/million cycles)										
(unaged)			14		0.8					5
(aged)					0.6					

8. The process of claim 1 wherein the annealing step is performed at a temperature greater than about 120°C.

5 9. The process of claim 1 wherein the annealing step is performed at a temperature of 120-170°C for 12-60 hours.

10 10. The process of claim 1 wherein the annealing step is performed for a time sufficient to form a cross-linked preform having an oxidation level of less than 0.2 carbonyl area/mil sample thickness after aging the cross-linked preform at 70°C for 14 days in oxygen at a pressure of about 5 atmospheres.

15 11. The process of claim 8 wherein the preform is irradiated with a dose of 1.5-6 Mrads and the irradiated preform is annealed at a temperature of 150-170°C for a period of 12-60 hours.

12. The process of claim 1 wherein the annealing step comprises melting the irradiated preform and applying an isostatic or hydrostatic pressure of 33-70 kpsi.

20 13. The process of claim 1 further comprising pre-annealing the preform at a temperature of 280°C - 355°C in an inert atmosphere without the application of external pressure for at least 0.5 hour prior to the irradiating step.

25 14. The process of claim 13 wherein the preform is pre-annealed at a temperature of about 320-355°C for at least 3 hours.

30 15. A process for preparing a medical implant having an improved balance of wear properties and oxidation resistance comprising the steps of:
irradiating a preform of ultrahigh molecular weight polyethylene to form free radicals;

✓ 24. The process of claim 15 wherein the annealing step is performed for a time sufficient to form a cross-linked preform having an oxidation level of less than 0.2 carbonyl area/mil sample thickness after aging the cross-linked preform at 70°C for 14 days in oxygen at a pressure of about 5 atmospheres.

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25. The process of claim 22 wherein the preform is irradiated with a dose of 1.5-6 Mrads and the irradiated preform is annealed at a temperature of 150-170°C for a period of 12-60 hours.

10 26. The process of claim 15 further comprising pre-annealing the preform at a temperature of 280°C - 355°C in an inert atmosphere without the application of external pressure for at least 0.5 hr prior to the irradiating step.

15 27. The process of claim 26 wherein the preform is pre-annealed at a temperature of about 320°C - 355°C for at least 3 hours.

28. The process of claim 15 wherein the annealing step comprises melting the irradiated preform and applying an isostatic or hydrostatic pressure of 33-70 kpsi.

20 29. The process of claim 15 wherein the annealing step comprises melting the preform at a temperature of 280 - 355°C.

30. The process of claim 29 wherein the annealing step comprises melting the preform at a temperature of 320 - 355°C.

25

31. A medical implant prepared according to the process of claims 1 or 15.

32. A cross-linked ultrahigh molecular weight polyethylene having a swell ratio of less than about 5 and an oxidation level of less than about 0.2 carbonyl area/mil sample thickness after aging the ultrahigh molecular weight polyethylene at 70°C for 14 days in oxygen at a pressure of about 5 atmospheres.

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INTERNATIONAL SEARCH REPORT

International Application No.

PCT/US 97/17776

A. CLASSIFICATION OF SUBJECT MATTER
IPC 6 A61L27/00 A61L31/00

According to International Patent Classification (IPC) or to both national classification and IPC

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)

IPC 6 A61L

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched

Electronic data base consulted during the international search (name of data base and, where practical, search terms used)

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
P, X	PATENT ABSTRACTS OF JAPAN vol. 097, no. 009, 30 September 1997 & JP 09 122222 A (KYOCERA CORP). 13 May 1997, see abstract	1-3, 7-9, 15-17, 21-23, 31
P, X	WO 97 29793 A (MASSACHUSETTS INST TECHNOLOGY ; GEN HOSPITAL CORP (US)) 21 August 1997 see page 6, line 1 - line 5 see page 7, line 12 - line 23 see page 12, line 7 - page 13, line 16 see page 14, line 2 - line 13 see page 17, line 1 - line 11 see claims 36-38, 71, 76, 79, 117	1-4, 7-9, 11, 15-18, 21-23, 25, 29, 31

☒ Further documents are listed in the continuation of box C.☒ Patent family members are listed in annex.

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Date of the actual completion of the international search

5 February 1998

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INTERNATIONAL SEARCH REPORT

Information on patent family members

International Application No

PCT/US 97/17776

Patent document cited in search report	Publication date	Patent family member(s)	Publication date
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		CA 2177042 A	28-03-96
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